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IDENTIFICATION OF BIOMES AND THEIR INDICATOR TAXA FOR CONSERVATION PLANNING: A CASE STUDY FROM CENTRAL INDIAN BIRDS

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Identification of biomes and their indicator taxa is a key component of spatial conservation plans, including rationalization of Protected Area (PA) network. Here, we seek to demonstrate the potential of Indicator Species Analysis (ISA) in identifying landscape-level biomes and their indicator taxa using birds of Central Indian Highlands in Madhya Pradesh. The study area was gridded into 284 contiguous quarter-degree cells, and data on distribution of 190 species of breeding land birds were collected for all the quadrats using a spatially hierarchical sampling scheme. We used a combination of cluster analysis and ISA to extract ecologically and statistically significant number of clusters that corresponded to distinct avian assemblages representing different biomes. In total, seven biome-restricted avian assemblages were identified along three gradients, namely vegetation, elevation, and rainfall. Among them, high-elevation moist deciduous forest harboured the largest number of biome-specialists with high indicator values. We then assessed the adequacy of the existing PA network with respect to coverage of the four forest biomes. Barring the low-rainfall teak forest, all the other biomes had more than 10% area under PA network. We discuss the conservation implications of this bias for central Indian avifauna and need for evolving multi-species criteria for prioritizing conservation areas.

Keywords: birds, tropical forests, Indicator Species Analysis, Protected Area network, biomes, Central Indian Highlands

INTRODUCTION

How to conserve biological diversity in an increasingly fragmented landscape of natural areas has always been a central challenge faced by conservationists and policy makers (Burbidge and Wallace 1995). Creation of a network of Protected Areas (PAs) that are relatively free from external interference remains the most efficient strategy (Trombulak *et al.* 2004; Locke and Dearden 2005), though alternative paradigms, such as participatory management are also being increasingly experimented, with mixed results (Mehta and Kellert 1998; Attwell and Cotterill 2000; Berkes 2004). But PA network cannot be infinitely large in size in a landscape like the Central Indian Highlands where a sizeable number of native people directly depend on forestry resources for sustenance, and demand for land is growing fast to meet their economic and livelihood needs. Therefore, conservationists prescribe that an optimal portion of wilderness area be brought under PA network that seeks to protect maximum biodiversity at a minimal socioeconomic cost (Trombulak *et al.* 2004). How much area would make up this optimum has been a matter of much debate and discussion. A broad consensus is that all the major biomes in a landscape should be adequately represented in a PA network, with minimum recommended area for each biome ranging from 10% (e.g., IUCN 1993) to 15% (e.g., European Commission 1992).

This biome-based approach is the key to developing an inclusive and representative PA network, as occurrence of surrogate taxa like an umbrella species or a flagship species often prompts declaration of a site as a Protected Area. Though surrogate taxa have an admirable role in garnering political and public support for setting aside exclusive areas for conservation (Walpole and Leader-Williams 2002), this approach is known to overlook other important species leaving several gaps in the PA network (see Caro and O'Doherty 1999; Roberge and Angelstam 2004). Therefore, a multi-species analysis is strongly recommended in identifying faunal biomes and in ranking sites for their conservation value (Reyers *et al.* 2002; Roberge and Angelstam 2004; Rodrigues *et al.* 2004; McCarthy *et al.* 2006).

The concept of biome has also been increasingly used as a biogeographical tool in conservation plans other than PA network analysis, either as a suite of landscape species (Coppolillo *et al.* 2004) or as a typology of eco-climatic communities (e.g., biomes as defined by BirdLife International; Islam and Rahmani 2004). In particular, the latter is one of the key criteria (A3) for identifying and developing a global network of Important Bird Areas.

Identification of ecologically significant biomes in a landscape is often a computationally challenging task that involves extensive use of multivariate statistical techniques. The assemblages of species characteristic of particular biomes are normally delineated by classifying sites into distinct clusters based on their similarity in species composition. Data on presence/absence (or relative abundance) of species in each of the sampling units (usually spatially contiguous grids at various scales) are analyzed using a classification technique like cluster analysis (Crowe and Crowe 1982; Muriuki *et al.* 1997) or an ordination method (Reyers *et al.* 2002). A thorny issue in such multivariate approach is the uncertainty over the optimal number of clusters (biomes) to be extracted for further investigations. In an attempt to overcome this problem, Dufrêne and Legendre (1997) developed a non-parametric Indicator Species Analysis (ISA) in which indicator values of all the species for each biome were computed along with their associated *P*-values at different cluster levels (through randomizations), and the most significant number of clusters would be the one at which the mean pooled *P*-value was observed to be the lowest. The indicator value of a species is expressed as a non-parametric function of site specificity and site fidelity. ISA has also been successfully adopted in several recent studies to identify unique sets of ecological communities and assemblages and their indicator taxa (Orrock *et al.* 2000; Heino *et al.* 2003; Venier and Pearce 2005; Shahabuddin and Kumar 2006).

Though ISA is conceptually simple and straightforward to use, its potential as a statistical tool in conservation science remains largely untested in India (barring Shahabuddin and Kumar 2006), in sharp contrast to its popularity elsewhere. Here, we seek to demonstrate its application in identifying landscape-level biomes and their indicator species using information on distribution of breeding land birds in tropical deciduous forests of central India. We then assess the adequacy of the existing PA network in the region vis-à-vis extent of coverage of these biomes.

METHODS

Study area

The study was conducted in Central Indian Highlands in Madhya Pradesh, which comprise the Satpura and the Vindhya ranges, and extend over an area of about 200,000 sq. km. The mean elevation of the hill ranges varies between 200-800 m, while some of the peaks in the western and central ranges exceed 1,000 m. The natural vegetation is predominantly made up of tropical dry- and moist-deciduous forests, characterized respectively by associations of teak (*Tectona grandis*) in western and central parts, and sal (*Shorea robusta*) in the east. These forests cover about 29% of the total land area (Source: IRS 1D-LISS III and FSI). There are 20 Protected Areas (i.e., 6 national parks and 14 wildlife sanctuaries) in the landscape and they occupy about 13% of the total forest area.

The study area was gridded into quarter-degree cells (15'x15') or quadrats (corresponding to Survey of India's 1:50,000 scale toposheets), with each quadrat measuring about 27 x 26.5 km in size (*c.* 715 sq. km.). This generated 284 contiguous grid-cells in total, and these quadrats formed the primary sampling units at which bird species richness and composition were mapped. To facilitate systematic bird surveys, these quadrats were grouped, *a priori*, into 11 coterminous landscape units ('regions') on the basis of natural vegetation, drainage, topography, and eco-climatic attributes, as follows: Malwa Plateau, Nimar Hills, Lower Narmada Valley, Betul Plateau, Sagar-Damoh Plateau, Satpura Plateau, Seoni-Chhindwara Plateau, Vindhya Scarplands, Kaimur Hills, East Maikal Range, and South Maikal Range (Fig. 1).

Birds

Data on species richness and composition of land birds that were known to breed in each quadrat were collected between April and July during 2002-2005. As the study area was too expansive to cover within a short period, we adopted a spatially hierarchical sampling protocol for each region with the following components: i) identification and mapping of key vegetation/habitat types in all the quadrats, ii) inventory-survey of breeding birds in each of the key vegetation types, and iii) within-region interpolation of species occurrence for all the quadrats from both these information layers. Accordingly, we collected data on bird-habitat associations from 36 major vegetation types using 'standardized area search method'. This technique involved laying of 5 ha transect-blocks in homogeneous forest types and inventorying all the bird species that were presumably breeding in the site by careful and meticulous search-walks till all the species were detected (see Jayapal *et al.* 2009 for details). In addition, numerous on-foot surveys were also undertaken to supplement the transect data, particularly in regions that were not covered by stratified sampling and in a few undersampled forest types. Matrices on bird-vegetation associations were then constructed for each region from these field-surveys. In the meantime, land cover information describing vegetation type and land use patterns were extracted from ground-truthed data collected from GPS-aided surveys in nearly all the quadrats. We also used the Survey of India's 1:250,000 and 1:50,000 toposheets to classify and estimate the extent of habitat/vegetation types in all the quadrats. Using both bird-vegetation matrices and vegetation maps generated for a region, data on distribution of breeding birds were spatially interpolated for each quadrat within the region. The final product comprising presence/absence data of bird species for each of the 284 quadrats was, later, contrasted with standard guides to birds of the Indian subcontinent (Ali and Ripley 1983; Grimmett *et al.* 1998; Rasmussen and Anderton 2005) and

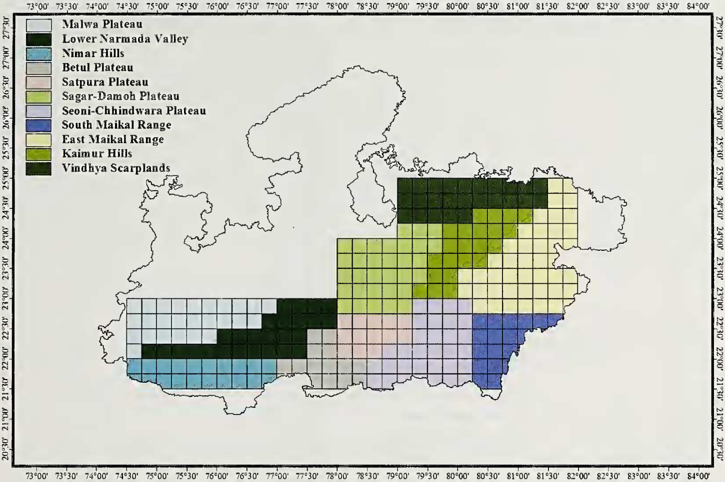

Fig. 1: Study area comprising Central Indian Highlands in Madhya Pradesh showing the quarter-degree cells and regions as classified in the study

with various regional bird lists for Central India published in the *Journal of the Bombay Natural History Society* (see Jayapal *et al.* 2005 for a list of these published resources). The comparison was necessary to check for gaps in species distribution maps as generated by our field surveys and to ascertain if the gaps were either due to sampling inadequacy or to recent fragmentations. If it was indeed the former (as would typically be expected of widespread and habitat-generalist species), we corrected for the gaps in the data.

Though the field-surveys targeted all the land bird species that were known to breed regularly in Central Indian Highlands, several species were excluded from the final analysis owing to insufficient data. These included all the three species of Buttonquail (*Turnix* spp.), Asian Palm-Swift (*Cypsiurus balasiensis*), Brahminy Kite (*Haliastur indus*), Forest Owlet (*Heteroglaux blewitti*), Ashy Woodswallow (*Artamus fuscus*), White-bellied Minivet (*Pericrocotus erythropygius*), Spotted Creeper (*Salpornis spilonotus*), and Green Avadavat (*Amandava formosa*). In total, 190 species of land birds for which we had adequate data were included in the analysis.

Data analysis

The data matrix describing the occurrence of 190 species of birds in 284 quadrats was first subjected to hierarchical clustering to classify the quadrats into biomes. As the data was binary in nature, Sørenson's distance measure was used in conjunction with flexible beta linkage ($\beta = -0.25$) to extract the clusters. This combinatorial strategy is often recommended as it turns out to be the most space-conserving clustering algorithm for binary data (McCune and Grace 2002). However, the actual number of statistically significant clusters present in the dataset would still remain unresolved, and we concurrently used Indicator Species Analysis (ISA) to choose the optimal number of biomes from the cluster dendrogram (Dufrêne and Legendre 1997; McCune and Grace 2002).

ISA is a non-parametric technique in which indicator value of a species for a given biome is computed as the product of 'faithfulness' (proportion of sites/samples within the biome in which the species is present) and 'exclusivity' (inverse of the total number of biomes in which the species occurs), expressed as percentage. The values range from zero (poorest

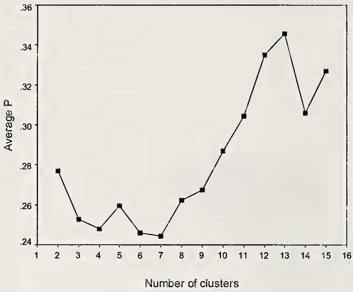

Fig. 2: Scatterplot showing the change in mean *P*-values of indicator values of bird species in response to different levels of clusters of quadrats

indicator) to 100% (perfect indicator). The statistical significance of indicator values is estimated by means of Monte Carlo randomizations. In order to ascertain the number of significant clusters to be extracted from the classification output, multiple runs of cluster analyses are carried out over a specified range of cluster-levels (usually from a few clusters higher than the 'expected level' down to two clusters). At each level of clustering, indicator values and their associated *P*-values of all the bird species are calculated and averaged across the biomes. The optimal number of clusters would then be determined as the one at which either the mean indicator value is noted to be the highest or the mean *P*-value is observed to be the lowest [see McCune and Grace (2002) for further details].

Accordingly, we ran a series of clustering (from 15 to 2 clusters) to classify the quadrats into biomes, and means of both indicator values and *P*-values (with 999 randomizations) were computed at each cluster level. The lowest *P*-value was used as the criterion to set the number of biomes to be identified and extracted. Both the cluster analysis and ISA were performed in the statistical program PC-ORD Version 4.0.

Quadrats representing different biomes were then mapped along with the existing PA network to calculate the proportion of area currently under legal protection in each biome. For this, the area of PA network in each biome was computed and contrasted with the total biome area [as estimated from Forest Survey of India toposheets and UMD-GLCF data (Hansen *et al.* 2000)]. If a PA was to be found extending over more than one quadrat, the area of the PA in

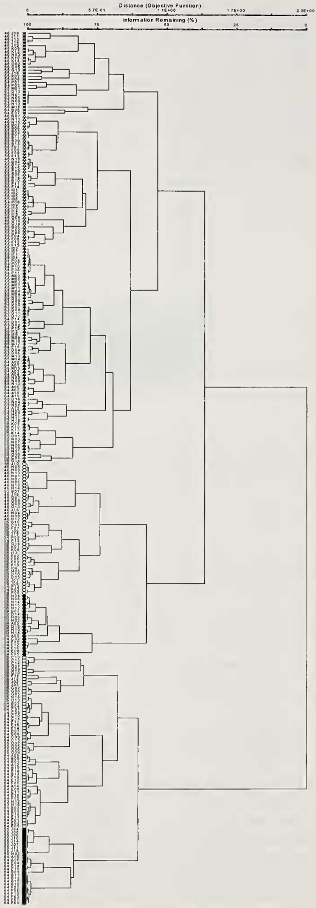

Fig. 3: Dendrogram showing the classification of quadrats (N = 284) into seven distinct biomes on the basis of bird species assemblages in Central Indian Highlands

Table 1: Major indicator birds of the four forest biomes of Central Indian Highlands along with their indicator values (IV) and associated *P*-values as estimated by ISA. Species marked * are endemic to the Indian subcontinent

Biome		Indicator Species	IV (%)	*P*
High-elevation moist deciduous forest	1.	Emerald Dove *Chalcophaps indica*	62	0.001
	2.	Brown Hawk-Owl *Ninox scutulata*	62	0.001
	3.	Hair-crested Drongo *Dicrurus hottentottus*	61	0.001
	4.	Puff-throated Babbler *Pellorneum ruficeps*	60	0.001
	5.	Oriental Scops-Owl *Otus sunia*	58	0.001
	6.	Brown-cheeked Fulvetta *Alcippe poioicephala*	58	0.001
	7.	Indian Scimitar-Babbler *Pomatorhinus horsfieldii**	58	0.001
	8.	Malabar Pied Hornbill *Anthracoceros coronatus**	58	0.001
	9.	White-throated Fantail *Rhipidura albicollis*	57	0.001
	10.	Rufous Woodpecker *Micropternus brachyurus*	56	0.001
	11.	Streak-throated Woodpecker *Picus xanthopygaeus*	56	0.001
	12.	Bonelli's Eagle *Hieraaetus fasciatus*	54	0.001
	13.	Oriental Turtle-Dove *Streptopelia orientalis*	54	0.001
	14.	Malabar Whistling-Thrush *Myophonus horsfieldii**	53	0.001
	15.	Ashy Drongo *Dicrurus leucophaeus*	52	0.001
Low-elevation moist deciduous forest	1.	Greater Racket-tailed Drongo *Dicrurus paradiseus*	42	0.001
	2.	Gold-fronted Leafbird *Chloropsis aurifrons*	41	0.001
	3.	Tickell's Flowerpecker *Dicaeum erythrorhynchos**	40	0.001
	4.	Orange-headed Thrush *Zoothera citrina*	37	0.001
	5.	Black-naped Blue Monarch *Hypothymis azurea*	37	0.001
	6.	Drongo Cuckoo *Surniculus lugubris*	36	0.001
	7.	Changeable Hawk-Eagle *Spizaetus limnaeetus*	35	0.001
	8.	Black-hooded Oriole *Oriolus xanthornus*	35	0.001
	9.	Red Junglefowl *Gallus gallus*	34	0.001
	10.	Crested Serpent-Eagle *Spilornis cheela*	32	0.001
High-rainfall teak forest	1.	Collared Scops-Owl *Otus bakkamoena*	27	0.001
	2.	Jungle Owlet *Glaucidium radiatum*	27	0.001
	3.	Black-backed Flameback *Chrysocolaptes festivus**	26	0.001
	4.	Pallas's Fish-Eagle *Haliaeetus leucoryphus*	26	0.001
	5.	Indian Pitta *Pitta brachyura**	26	0.001
	6.	Indian Grey Hornbill *Ocyceros birostris**	23	0.001
	7.	Plum-headed Parakeet *Psittacula cyanocephala**	22	0.001
	8.	White-bellied Drongo *Dicrurus caerulescens**	22	0.001
	9.	Yellow-fronted Pied Woodpecker *Dendrocopos mahrattensis*	20	0.001
	10.	Grey-bellied Plaintive Cuckoo *Cacomantis passerinus**	20	0.001
Low-rainfall teak forest	1.	Tawny-bellied Babbler *Dumetia hyperythra**	26	0.001
	2.	Oriental Honey-Buzzard *Pernis ptilorhyncus*	24	0.001
	3.	Jungle Prinia *Prinia sylvatica**	23	0.001
	4.	White-eyed Buzzard *Butastur teesa*	21	0.001
	5.	Jungle Bush-Quail *Perdicula asiatica**	20	0.001
	6.	Indian Pygmy Woodpecker *Dendrocopos nanus**	20	0.001
	7.	Small Minivet *Pericrocotus cinnamomeus*	20	0.001
	8.	White-browed Fantail *Rhipidura aureola*	20	0.001

each quadrat would be calculated separately. This was necessary, as a PA might sometimes stretch across two adjacent quadrats, which were assigned to two different biomes in the analysis. We applied the IUCN's target of 10% area (Locke and Dearden 2005) as the minimum benchmark for assessing the adequacy of PA network in each biome.

RESULTS

Classification of biomes

When the pooled means of *P*-values associated with the indicator values of bird species, as computed by ISA, were examined against the number of cluster-levels of quadrats, the lowest *P*-value was obtained for seven clusters

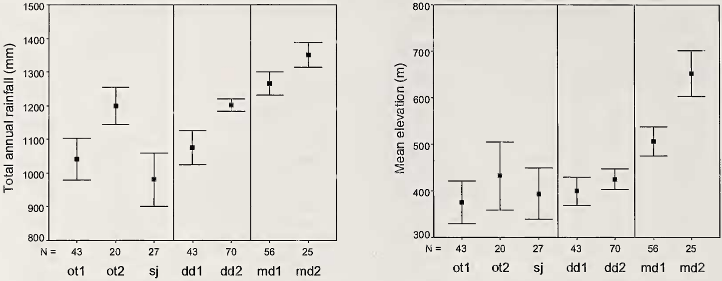

Fig. 4: Comparison of environmental attributes of the seven biomes as obtained in the hierarchical clustering of quadrats based on bird distribution. The error bars correspond to lower and upper 95% CI about the mean. The abbreviations of biomes are as follows: ot = open tracts, sj = scrub jungle, dd = teak-dominant deciduous forests, and md = moist deciduous forests

(Fig. 2). Subsequently, a final run of cluster analysis with *a posteriori* solution of seven clusters was carried out. It was evident from the resulting dendrogram (Fig. 3) that these seven groups corresponded to four vegetation types (as deduced from the UMD-GLCF land cover/use data): open tracts, scrub jungle, teak-dominant deciduous forest, and moist-deciduous forest. To aid further interpretation of the clusters, the relative positions of these groups along some environmental gradients were examined by comparison of group-means and degree of overlaps in 95% confidence intervals (CI) about the mean. The clusters were observed to differ significantly along either rainfall or elevation (Fig. 4), implying the following seven biomes: open moist tract, open semi-arid tract, scrub jungle, low-rainfall teak forest, high-rainfall teak forest, low-elevation moist deciduous forest, and high-elevation moist deciduous forest. Out of these, only four biomes were considered for further investigations into adequacy of PA network. Open tracts and scrub jungle were omitted from analysis as they were essentially human-modified environments dominated by generalist and commensal species of birds.

Table 2: The proportion of area under PA network in each of the four forest-biomes of Central Indian avifauna.

Biome	Total forest area (sq. km)	Forest area under PAs (sq. km)	% Area under PA network
High-elevation moist deciduous forest	9,512	1,876	19.72 %
Low-elevation moist deciduous forest	18,741	2,256	12.04 %
High-rainfall teak forest	16,501	1,975	11.97 %
Low-rainfall teak forest	8,883	607	6.83 %

Indicator species of biomes

Indicator values (IV) of all the bird species were computed in ISA for each biome and only those species with statistically significant values ($P < 0.01$) were considered for further screening. Species were assigned as indicator taxa to the biome for which the IV was observed to be the largest. Of all biomes, high-elevation moist deciduous forest was characterized by species with very high indicator values. On the contrary, both the biomes of teak forests were marked by generally low mean indicator values (Table 1).

Adequacy of PA network

When the boundaries of the existing PAs, comprising national parks and wildlife sanctuaries, were overlaid on the map of quadrats representing the four biomes, it was observed that all the biomes were adequately covered under PA network (i.e., > 10% of area) barring the low-rainfall teak forest with a shortfall of about 3% area as per IUCN norms. In contrast, the high-elevation moist deciduous forest had a fairly large proportion of area (*c.* 20%) under protection (Table 2).

DISCUSSION

The study amply demonstrates the potential of Indicator Species Analysis in eliciting the structure and composition of biome-restricted assemblages of species in a landscape, and how these faunal assemblages and biomes can be objectively used in assessing the adequacy of conservation efforts in the region. Analysis of geographical distribution of the breeding land birds in Central Indian Highlands using hierarchical clustering and ISA has revealed presence of seven distinct landscape units. These biomes representing unique assemblages of central Indian avifauna are evidently organized along three environmental gradients: vegetation, elevation and rainfall. The role of environment in structuring vegetation communities and secondarily the associated faunal assemblages has been acknowledged as one of the unfailing patterns in macroecology (Hawkins *et al.* 2003; Whittaker *et al.* 2005).

The tropical seasonal forests of central India show a marked gradient of moisture ranging from extremely dry vegetation in the west (e.g., Malwa Plateau) to moist forests in the south-east (e.g., Maikal Ranges), heavily influencing the composition and proportion of floristic associations alongside. For example, sal (*Shorea robusta*) dominates the climax vegetation of the moist deciduous forests in the east and south-eastern parts of Madhya Pradesh, and teak (*Tectona grandis*) forms core of the vegetation associations among the dry deciduous forests in central and western parts of the state. These changes in floristic composition are often accompanied by corresponding changes in bird composition as well, sometimes mediated through species replacements, within closely related sister-taxa [e.g., Red Junglefowl (*Gallus gallus*) in the sal, and Grey Junglefowl (*Gallus sonneratii*) in the teak biotopes]. Not surprisingly, forest physiognomy emerges in the study as a key ecological factor that defines the biomes of Central Indian Highlands. In addition, birds of moist deciduous forests show two distinct assemblages in response to elevational gradient, and differences in rainfall seem to describe the two biomes of teak forests.

Among the four forest biomes of central Indian avifauna, high-elevation moist deciduous forests are characterized by bird species with extraordinarily high indicator values, signifying the uniqueness of the biome with a large number of biome-specialists (IV > 50% for 17 species). These include Malabar Pied Hornbill (*Anthracoceros coronatus*), Oriental Scops-Owl (*Otus sunia*), Ashy Drongo (*Dicrurus leucophaeus*), Malabar Whistling-Thrush (*Myophonus horsfieldii*), Velvet-fronted Nuthatch (*Sitta frontalis*), Red-whiskered Bulbul (*Pycnonotus jocosus*), Spotted Babbler (*Pellorneum ruficeps*), Indian Scimitar-Babbler (*Pomatorhinus horsfieldii*), and Brown-cheeked Fulvetta (*Alcippe poioicephala*). Biogeographically, birds of high-elevation moist deciduous forest biome are significant as they represent remnants of the avifauna of wet humid montane forests of the past that acted as a dispersal highway for Indo-Malayan fauna from the Eastern Himalayas to the Western Ghats according to the 'Satpura Hypothesis' (Ali 1949; Karanth 2003).

The low-elevation moist deciduous biome is noteworthy for its regional importance as it is by far the most dominant in area of extent in Central Indian Highlands. Though the cumulative mean indicator value of the biome is marginally less than its high-elevation counterpart, some species of birds do show a great degree of affinity with indicator values exceeding 40%. Prominent among the birds that almost exclusively breed in low-elevation moist deciduous forests are Red Junglefowl (*Gallus gallus*), Drongo-Cuckoo (*Surniculus lugubris*), Indian White-rumped Spinetail (*Zoonavena sylvatica*), Changeable Hawk-Eagle (*Spizaetus cirrhatus*), Gold-fronted Leafbird (*Chloropsis aurifrons*), Black-naped Blue Monarch (*Hypothymis azurea*), and Chestnut-bellied Nuthatch (*Sitta castanea*).

Unlike the avifauna of moist-deciduous forests, both the high- and low-rainfall biomes of teak forests are generally marked by bird species with moderate indicator values. However, they form one of the most ubiquitous assemblages of birds that one encounters in the central Indian landscape. In fact, high-rainfall teak forests are second only to low-elevation moist deciduous forests in geographical extent, covering over an area of nearly 16,000 sq. km. An interesting feature common to indicator birds of both the teak forest biomes is that they shelter a good proportion of species endemic to the Indian subcontinent [e.g., Black-backed Flameback (*Chrysocolaptes festivus*), Indian Grey Hornbill (*Ocyceros birostris*), Indian Pitta (*Pitta brachyura*), White-bellied Drongo (*Dicrurus caerulescens*) among the breeding birds of high-rainfall teak biome, and Jungle Bush-Quail (*Perdicula asiatica*), Indian Pygmy Woodpecker (*Dendrocopus nanus*), Jungle Prinia (*Prinia sylvatica*), and Tawny-bellied Babbler (*Dumetia hyperythra*) in low-rainfall teak forest biome]. This is probably a reflection of the fact that forests in the Subcontinent are chiefly dry deciduous in nature. Thus, the preponderance of endemic species as indicator taxa makes both high- and low-rainfall biomes of teak forests biologically significant and calls for adequate conservation measures.

Indicator Species Analysis is a promising tool in macroecological applications, and is being increasingly used in place of classification and ordination methods (Dufrêne and Legendre 1997; Orrock *et al.* 2000; Heino *et al.* 2003; Venier and Pearce 2005). One of the reasons for its popularity is that ISA is relatively free of many of the key assumptions and data-constraints traditionally associated with multivariate techniques; for example, assignment of a species to a biome in ISA is independent of occurrence or abundance of other members of the assemblage unlike TWINSPAN (Dufrêne and Legendre 1997), and ordination method like Canonical Correspondence Analysis would require unimodal response of species to environmental gradients, an assumption often difficult to meet with ecological data (McCune and Grace 2002; Reyers *et al.* 2002). Some of the other emergent properties of ISA that favour its widespread use are: straightforwardness of distribution algorithms, flexibility with presence/absence data, tractability of computations, use of objective criteria to identify and retrieve indicator species, incorporation of randomization methods to evaluate statistical significance of indicator scores, and compatibility with spatial data. The present study has also demonstrated the usefulness of ISA in determining the cutoff level in a dendrogram to extract meaningful clusters, as originally proposed by Dufrêne and Legendre (1997) in their landmark paper.

Identification of biomes using multiple taxa is immensely preferable to single-species approach (e.g., umbrella or flagship species) as the latter frequently fails to ensure adequate protection for several key species and ecosystems (Roberge and Angelstam 2004; Rodrigues *et al.* 2004; McCarthy *et al.* 2006). This is well-illustrated by the findings of the current investigation in which low-rainfall teak forests emerge as the only biome in Central Indian Highlands that is under-represented in PA network. Nearly restricted to western Madhya Pradesh, these forests have been overlooked for long by PA managers evidently because they do not hold any significant populations of tiger, a species that almost solely inspires and drives conservation planning and reserve network in central India. It was, therefore, a revelation that when the critically endangered Forest Owlet (*Heteroglaux blewitti*) – a species endemic to Central India, was rediscovered in 1997 after a gap of 113 years (King and Rasmussen 1998), these low-rainfall teak forests were found to be its core habitat (contrary to original descriptions of 19th century records). The fact that a majority of these sites which are currently holding the fragmented populations of Forest Owlet lie outside PA network (Ishtiaq and Rahmani 2000; Mehta *et al.* 2007) highlights the severe bias in reserve planning in Central Indian Highlands. Though the landscape boasts of 13% forest area under PA network, they are not equitably distributed across different biomes. For example, high-elevation moist deciduous forests have a remarkably high proportion of about 20% area under the network exceeding the IUCN's minimum requirement. It is also to be noted here that all the PAs in this biome, including Kanha and Bori-Satpura Conservation Areas, were created almost exclusively for the cause of the tiger, and these PAs are marked by areas (*c.* 1,500 and 1,050 sq. km respectively) much larger than the average area of PAs (383.2 sq. km) in Central India. Despite this prejudice, it is heartening to find that all the biomes of central Indian avifauna, barring low-rainfall teak forest, are adequately protected with more than 10% of area in each biome currently under PA network. Ironically, this is again attributed to the arguable role played by charismatic taxa like tiger. It serves to highlight the political relevance of flagship species in our conservation efforts even as we begin to recognize the need for multi-species approach (see Walpole and Leader-Williams 2002).

The application of Indicator Species Analysis in conjunction with reserve selection algorithms has gained widespread approval for its biome-oriented approach to rationalization of PA network. However, this approach suffers from a conceptual issue in the sense that most of the studies are invariably restricted to a particular taxon and congruence across different taxa in spatial patterns of species diversity or endemism is not always supported by empirical data (Prendergast *et al.* 1993; Hopkinson *et al.* 2001; Rey Benayas and de la Montaña 2003). Future studies should, therefore, strive to reach solutions universally applicable to all major taxa by developing appropriate sampling protocols that would require data on distribution of multiple taxa from a landscape.

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